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Oxygen Enriched Atmosphere Roasting

Clarence Wells Jr

OXYGEN ENRICHED ATMOSPHERE ROASTING

A Thesis

Submitted to

the Department of Metallurgy

Montana School of Mines

In Partial Fulfillment

of the Requirements for the Degree

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GENERAL INTRODUCTION

The possible benefits of oxygen enriched atmosphere roasting have been known to metallurgists for many years, but only since the development of equipment and processes to produce cheap oxygen in very large amounts has much serious consideration been given this matter.

In the early 1930's the Germans started work on producing cheap oxygen for metallurgical uses.[1] The Russians have also done much work in this field, but very little information has been published by either country.

A German, Mathias Frankl, suggested the use of regenerators on a short reversing cycle to transfer refrigeration, rather than continuous counterflow heat exchangers like steam condensers. He devised a low-pressure cycle that produced 98% oxygen for about one-third the power consumption of the earlier high pressure cycles.

At the present time, medium sized plants in the United States are producing oxygen for $6.00 per ton, but these plants would not be large enough for metallurgical operations. A plant is being built in Brownsville, Texas which is the size required for metallurgical operations, and the builders estimate the oxygen will be produced for $2.00 per ton. The capacity of this plant will be 2,000,000 cubic feet per hour. Two dollars per ton of oxygen compares favorably with the German cost figures. Oxygen at twice this figure would still make oxygen atmosphere roasting an attractive possibility. Experts on oxygen production say that efficiency will increase with the size of the plant and thereby lower the cost per unit weight of oxygen. The requirements of only a small amount of storage space and the use of low pressure systems help greatly in reducing oxygen costs.

In 1935, Mr. T. E. Norman of Toronto, Canada made a series of calculations on different concentrates to show the amount of heat that would be produced by roasting a high sulphide concentrate in an oxygen enriched atmosphere.[2] The concentrates used by Mr. Norman for his calculations varied widely in composition and mineral content, but all had a high sulphur content. His results indicated that the heat produced was theoretically great enough to roast and smelt the concentrates without the use of extraneous fuel. As far as known, there were no actual experiments performed on this problem at that time, and there are still no published results of work done.

Very recently the Consolidated Mining and Smelting Company of Canada has been doing work in their plant at Trail, B. C. on the roasting of zinc concentrates in an oxygen atmosphere, but at the present time they have released very little information on their tests. They have, however, stated that their tests are proving to be very encouraging. Shaft roasters are being used for the work at Trail. The primary objectives of the work are to reduce the circulating dust load and to get better operational control.

The actual tests in this investigation were run in a small shaft roaster, which is described on page 12, with copper sulphide concentrates of the analysis given on page 14, as the feed. The tests were run with the idea of determining and studying the problems that would be encountered in oxygen enriched atmosphere roasting as well as studying the physical and chemical properties of the roasted product. It was undersood that the size of the equipment used would prevent the obtaining of results which would hold for plant practice, but they would at least give an indication as to what might be expected.

THEORY

Enriched atmosphere roasting in this case refers to the roasting of copper sulphide concentrates in an atmosphere of oxygen rather than in air. Oxygen is used in order to expose the concentrates to a maximum amount of oxidizing atmosphere with a minimum amount of gases being introduced into the roasting chamber.

Since air is approximately seventy-nine per cent nitrogen, it is necessary to introduce four parts of this gas into the roasting chamber for every one part of oxygen. The use of pure oxygen as the roasting atmosphere would reduce the volume of gases four times. Large amounts of heat are required to bring the nitrogen in air up to the temperature of the roasting operation, and most of this heat is lost through the flue gases.

The high dilution of the oxygen in air causes the oxidation reactions in roasting to take place very slowly and results in higher losses of heat by radiation, convection, and conduction. If the heat producing reactions were rapid enough, most of the heat would be maintained by the particles instead of being transferred to the furnace and the gases. An oxygen enriched atmosphere would greatly increase the speed of reaction and thereby reduce these losses.

An oxygen atmosphere would greatly reduce the height of the shaft roaster required, because the concentrates would be subjected to a great amount of oxidation in a very short fall.

There are several factors which affect the rate and completeness of the oxidation reactions, but the three most important are the size of the particles to be roasted, the temperature of the roasting chamber, and the oxygen content of the roasting atmosphere. A finer feed tends to give a faster and more complete reaction, because there is a greater surface area exposed per unit weight of material. If the particles are coarse, there will be a core at the center which will not be oxidized unless the roasting takes place over an extended period of time. A higher temperature in the roaster will give a faster and more complete oxidation of the sulphide material and greatly reduce the core effect. A high oxygen content in the roasting atmosphere causes the oxidation reactions to take place more rapidly and go more nearly to completion.

There are large amounts of heat liberated in the oxidation of sulphide concentrates. Calculations show that theoretically there is enough heat produced by the oxidation of most high sulphide concentrates to produce a matte and a slag without the use of extraneous fuel. Such an operation would require a furnace which would have very low heat losses and still meet other requirements of the process. Heat would be removed from the operation by the matte, slag, and flue gases as well as by radiation, conduction, and convection. It would be impossible to nulify these losses, but they could be minimized by the use of proper equipment, and ideal operating conditions. The use of an oxygen atmosphere would greatly reduce the heat losses and thereby make more heat available for the actual roasting and smelting. The lack of a suitable shaft roaster, which would minimize these losses, has been one of the factors that has retarded work in enriched atmosphere roasting.

A good furnace would be one which would permit the particles to fall freely and be exposed to the maximum amount of oxidation but still keep heat and dust losses at a minimum. Another requirement of the furnace would be that it have a suitable hearth for the collection of the calcine which would minimize calcine heat losses.

It is not possible to estimate the capacity of a furnace using an oxygen enriched atmosphere until actual operating conditions are set. All conditions which can be varied during the operation are very important in arriving at such a figure. In addition, the sulphur content of the feed and the calcine is very important. The smaller the percentage of sulphur that has to be removed, the greater the capacity of the furnace. A concentrate comparatively low in sulphur that was to produce a calcine relatively high in sulphur could be put through the furnace at a high rate. A higher oxygen content in the roasting atmosphere causes a faster and more complete oxidation, and, as a result, increases the capacity of the roaster. Wall friction, the height of the shaft, the use of counter current or concurrent draft, dust losses, and operating temperature will affect the capacity of the furnace.

With a high shaft, concurrent draft could give greater capacity, because the dust loss would be much less. A high shaft would be required, because the material would not be exposed to as much oxidizing atmosphere per unit distance of fall as it would be with counter current draft. A counter current draft reduces the rate of fall of the particles, while concurrent draft increases it.

Wall friction would be greatly reduced if the shaft were sufficiently large in diameter, but it would still have an effect on capacity. Accretions which might build up on the walls would increase the wall friction considerably.

A high shaft increases the time for the oxidation reaction and thereby causes it to go more nearly to completion. A more complete reaction permits an increase in the rate of feeding.

A high operating temperature causes a rapid and more complete oxidation of the sulphides and increases capacity. The temperature of the furnace is affected by the rate at which the concentrates are fed.

Counter current draft causes a high circulating dust load and cuts down the overall capacity of the furnace. A finely-ground feed also increases the circulating dust load, but this might be overbalanced by the speed and completeness of the oxidation of fine material.

A dry feed, which is free of lumps, is preferable for a shaft roaster. If water were introduced with the feed, a large amount of heat would be required to vaporize it, and the vapor would increase the volume of gases to be handled. Lumps in the feed cause the inner material to be protected from the oxidizing atmosphere and remain as sulphides. Lumps in dry feed could be removed by passing the material through a ball mill or a set of fine rolls before it was introduced into the furnace.

Moist feed could possibly be used if extra heat were added to the operation and a method could be devised for preventing lumps. However, the addition of extra heat and the larger amounts of gases to be handled would help destroy the advantages of the enriched atmosphere.

There is a limit to the fineness of the feed, because extremely fine material would cause higher dust losses and be expensive to produce. The fineness of the material to be roasted would be determined by previous treatment and methods of concentration. Flotation concentrates would probably be sufficiently fine to give good results in this type of roasting.

There are several possibilities for the subsequent treatment of the product from a shaft roaster using an oxygen atmosphere. The treatment which seems most feasible would be to use a shaft roaster in connection with a reverbatory and produce a copper matte which could be treated in a converter. However, such possibilities as a dead roast and subsequent leaching, the formation of a matte and a slag in the hearth of the roaster, and roasting to a low sulphur calcine, which could be mixed with green concentrates to control the copper-sulphur ratio for the reverbatory feed, are worth some consideration.

If the shaft roaster and the reverbatory were used in connection, concurrent draft would probably prove more satisfactory, because any fine material would be drawn into the collecting hearth or into the reverbatory. Any impurities which were volatile would pass off with the gases from the reverbatory. If counter current draft were used, the dust would have to be recirculated to the furnace. However, this method might give better removal of impurities. The calcine leaving the roaster would be very hot and could be smelted by a small addition of heat. The sulphur content could be controlled in the shaft so that a matte of the proper grade could be produced.

The fluxes which would be required for the smelting operation could be added to the roaster feed or directly to the reverbatory.

Using a roaster with an oxygen enriched atmosphere and a reverbatory in combination will greatly increase the capacity of the reverbatory.

The possibility of obtaining a dead roast or a near dead roast in a shaft roaster using an oxygen enriched atmosphere is quite good, but subsequent leaching and recovery of copper present another problem. In obtaining complete oxidation of copper sulphide minerals, large amounts of pyrite and any other sulphides present would be oxidized. The copper oxide would be soluble in dilute sulphuric acid, but the other oxides would also be quite soluble and would present a serious problem of purification to be taken care of before the copper sulphate solution could be electrolyzed. If the problem of purification could be handled economically, leaching and electrolysis would be the best and cheapest method for handling the roasted product.

It would be possible to obtain a low sulphur calcine from the roaster and mix it with green concentrates to obtain the desired copper-sulphur ratio for reverbatory feed, but it would probably be better to increase the feed to the roaster and control the copper-sulphur ratio in the furnace and have the advantages of a preheated, uniform feed for the reverbatory.

In addition to the saving of heat already discussed, enriched atmosphere roasting offers several other advantages which are: low space requirement, high SO_2 content in the flue gases, and flexibility of the operation.

Space requirement per unit weight of material treated would be much less for a shaft roaster with an oxygen atmosphere and a reverbatory used in combination than it would be with the conventional multiple hearth roaster and a reverbatory operating as separate units. Not only would the shaft roaster have a capacity many times that of a multiple hearth furnace of the same size, but the capacity of the reverbatory would be increased by the heat content of the material fed into it. The increase in capacity would reduce the cost of equipment required to treat a certain amount of material.

The gases from a roasting operation which was carried on in an oxygen atmosphere would have a very high SO_2 content and would be very suitable for the production of sulphuric acid, elemental sulphur, or liquid SO_2. In many places there is a good market for such products.

A shaft roaster using an oxygen atmosphere would give a flexible operation, because of the fact that there are several control factors which could be varied to obtain the desired results. The oxygen content of the roasting atmosphere, the rate of feeding material to the furnace, the amount of draft, and the furnace temperature could all be varied to obtain a desired product.

There are problems which are encountered in any pyrometallurgical operation, and enriched atmosphere roasting would be no exception. Accretions would probably form in the hottest section of the furnace, because the temperature there is near that of the fusion point for the material being roasted, but the removal or prevention of such accretions should not be unsurmountable.

If counter current draft were used, the zone of combustion would probably move up and down the shaft with each variance in feed or in oxygen content of the chamber atmosphere. If the movements occurred rapidly enough, explosive waves might be generated. In extreme cases, if the feed were shut off long enough to permit the chamber to fill with oxygen, a serious explosion might occur when the feed was turned on again. Such a danger might possibly be avoided if the material were ignited as soon as it entered the chamber instead of dropping to a point where the furnace temperature would be great enough to cause ignition. It might be possible to solve the problem of preventing explosions and lowering the circulation dust load, but at the outset, concurrent draft seems to show greater possibilities. However, the thermal advantages of counter current draft at least warrant giving it a fair trial.

FURNACE DESIGN

A small shaft roaster was built in the laboratory for use in this investigation.

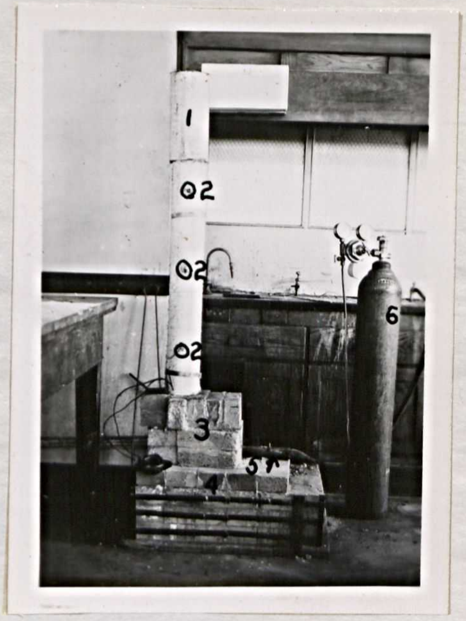

FIGURE I
SHAFT ROASTER

1. Shaft	4. Foundation
2. Thermocouple Wells	5. Burner
3. Hearth	6. Oxygen Supply

The shaft for the roaster was made from a piece of two inch wrought iron pipe which was four and a half feet in length. Three thermocouple wells were placed in the shaft at one foot intervals with the upper one being one foot down from the top of the shaft. The wells, consisting of three, four inch pieces of quarter inch pipe sealed on one end, were inserted into the shaft to a depth of one inch. The thermocouples were inserted into the wells to measure the temperature at the different points in the shaft.

The furnace had a rectangular, fire brick base which was 36" x 30" x 16". This large base served as a foundation for the furnace and prevented large amounts of heat from being transferred to the floor.

The hearth for the furnace was made by forming fire clay between fire brick which were layed flat in a "U" shape and were stacked two high. The legs of the "U" were drawn in slightly near the base so as to make the hearth wider at the open end. The fire clay was built up inside the bricks to give a hearth which tapered in width from 6" in the front to 2" in the back and was "U" shaped in vertical cross section. The hearth sloped toward the front so the calcine could be easily removed. The fire clay hearth had many cracks, so alundum cement was used to fill them and put a thin coat over the entire hearth. The hearth was covered by a single layer of fire bricks which were stood on edge, and the front opening was covered by merely setting a brick over the opening. Fire clay was used as the cementing material throughout the furnace except for the alundum used as mentioned.

The shaft was set over the back end of the hearth and was held in place by two layers of bricks around the base of it. Fire clay was used to pack between the bricks and the shaft. The shaft was wrapped with several layers of asbestos paper which in turn had an asbestos pipe covering over it. The asbestos paper alone allowed excessive heat losses, but the combination of paper and pipe covering proved quite satisfactory. The pipe wrapping was held to the shaft by small brass bands. Holes were punched through the covering for the thermocouple wells.

The burner for furnishing heat to the furnace was placed in the front end of the hearth and was a blast type using natural gas and compressed air.

The oxygen was fed into the front end of the hearth from a high pressure tank by means of a piece of glass tubing which was widened to three-fourths of an inch at the discharge end so as to reduce the pressure and the amount of draft. Without a reduction in gas pressure, excessive amounts of material were blown out the top of the stack.

FEED FOR TESTS

The actual tests for this investigation were made on a copper sulphide concentrate which was a grab sample of the feed to the multiple hearth roasters at the Anaconda Reduction Works. The concentrates showed the following analysis: 23.184% copper, 23.08% iron, 32.993% sulphur, 2.045% arsenic, and 14.20% insol.

In an investigation such as this, it is important to know the minerals present and the amount of each. The amount of pyrite is of exceptional importance, because large amounts of heat can be obtained from the oxidation of this mineral. In order to determine the minerals and their amounts, several mineral counts were made with the aid of a binocular microscope. Small samples of the concentrates were mounted in lucite briquettes for the mineral counts. The results of the mineral count were combined with the results of the analysis, and the following mineral content was arrived at: 46% pyrite, 20% chalcocite, 11% enargite, 3.0% bornite, 1.0% chalcopyrite.

TABLE I

DISTRIBUTION OF ELEMENTS IN CONCENTRATES

MINERAL	% Cu	% Fe	% S	% As
Enargite	5.2		3.6	2.0
Chalcopyrite	0.4	0.4	0.2	
Bornite	1.9	0.3	0.7	
Pyrite		21.0	24.5	
Chalcocite	15.7	1.1	3.9	

A screen analysis was run on the concentrates, because tests were to be run to see if the fineness of the feed to the furnace had a noticeable effect on sulphur removal.

TABLE II

SCREEN ANALYSIS OF FEED

Mesh	Wt. (gms)	Wt. %	Cumulative %
+ 48	0.9	0.18	0.18
-48 + 65	26.1	5.22	5.40
-65 + 80	43.1	8.62	14.02
-80 + 100	67.4	13.47	27.49
-100 + 150	55.8	11.18	38.67
-150 + 170	112.6	22.50	61.17
-170 + 200	121.5	24.31	85.48
-200 + 250	20.2	4.04	89.52
-250 + 270	9.1	1.82	91.34
-270 + 400	15.1	3.02	94.36
- 400	28.2	5.64	100.00
	500.0	100.00	

PRELIMINARY TESTS

A small resistance furnace was used to run preliminary roasting tests on the copper sulphide concentrates which were to be used in this investigation. The furnace was heated to about 850 degrees Fahrenheit before the concentrates, which were in small alundum boats, were placed in the furnace. Oxygen was admitted to the furnace through one end of the quartz tube at a rate great enough to remove the SO_2 from the furnace as fast as it was formed so that a maximum amount of oxidation would take place. Care was taken, however, not to have a passage of oxygen so great that it would cause excess cooling. Tests showed that the material could be fused into a strong sinter if the conditions were right.

For the first tests, the bottom of the alundum boat was covered with a very thin layer of concentrates and placed in the furnace for three minutes. The product from these tests was a slightly fused material with a sulphur content of four per cent. Examination showed that the material was in small globules and that the fused material formed a shell and protected the sulphides on the inside from being oxidized.

For the next tests, the amount of concentrates was increased so that the alundum boat was nearly full. The rate of oxygen flow was increased enough to remove the SO_2 as it was formed. The product from these tests contained approximately the same amount of sulphur as before, but it was fused into a much stronger sinter. The greater fusion in this group of tests indicated that more heat from the oxidation reaction was retained by the concentrates, because the original furnace temperature was the same in both cases, and there was no other source of heat. These results at least indicate that the heat losses become less per unit weight of material roasted as the rate of feeding and of oxidation increase up to a certain limit. The losses increase at a slower rate than does the amount of heat produced by the oxidation of the sulphides.

A third test was run at the same furnace temperature but with air rather than oxygen as the atmosphere. The alundum boats were filled with the same amount of material as in the second test and allowed to roast for the same length of time. The roasted material was not fused and had a sulphur content of 22.5 per cent which was much higher than in the previous tests. This indicated that the heat which fused the concentrates in the first two tests was produced by the oxidation reaction.

These tests were run to give an indication of what might happen and what the product might be like if sulphides were roasted in an oxygen atmosphere. It was realized that the particles were not exposed to as much oxidation in the alundum boat as they would be during a fall in a shaft roaster, and the results were evaluated accordingly.

TESTS

The heat and oxygen were admitted to the furnace through the front opening in the hearth while the concentrates were hand fed to the top of the shaft. A temperature of 950°F was reached in the hearth before any concentrates were fed into the shaft. A temperature of 950°F in the hearth would give a temperature of 400°F at the top of the shaft, 425°F one foot down from the top, 650°F two feet down, and 775°F three feet down. After a uniform temperature was reached in the shaft, there was no measurable change when concentrates were being fed to the furnace. Accretions which built up on the thermocouple wells would probably prevent small changes from registering.

There was no way to keep the rate of feeding the same for any extended period because of the method of hand feeding used. The concentrates were placed in a scoop which was held at the upper edge of the shaft and vibrated so as to have a continual feed that was as uniform as possible.

It was impossible to keep the feed exactly uniform. Any variation in the rate of feeding would have an effect on the physical and chemical properties of the calcine.

The rate of oxygen flow to the furnace was controlled so that there was a slight excess of oxygen in the gases exhausted from the shaft. The slight excess of oxygen would give a maximum amount of oxidation and not give a great cooling effect.

No attempt was made to determine the amount of heat added to the furnace or the heat losses. A check was made, however, to see if there was any noticeable change in the furnace temperature during the time of feeding.

A test was made by feeding concentrates to the furnace under the conditions described and for a period of five minutes. The calcine was removed from the furnace throughout the test to prevent the roasted material from absorbing heat while in the hearth. A calcine which was more nearly representative of the roasting operation was thus obtained. The calcine obtained from this test contained 2.3% S, 26.85% Cu, and 26.7% Fe and was fused into small globules which were quite hard and compact.

The physical condition of the calcine indicated that the material had reached a temperature which was high enough to cause partial fusion. A small amount of additional heat would cause complete fusion.

The globules formed showed that it would be difficult to remove the remaining sulphur, because the inner material would be protected from complete oxidation.

The analysis of the calcine showed that the concentrates would have to be fed at a much greater rate if the calcine were to be used in a reverbatory for making matte. The present practice with this same concentrate is to have 13% sulphur in the calcine after the fluxes have been added. A decrease in the oxygen content of the roasting atmosphere would also raise the sulphur content of the calcine.

A sample of the dust blown from the stack during this test was analyzed and showed a sulphur content of 19%. The high sulphur content indicated that the material fell only a short distance into the shaft and was only slightly oxidized.

The next test which was run with the same furnace conditions, but with feed which was all minus 100 mesh. The object of this test was to see if a finer feed would give better sulphur removal. The only noticeable difference in the operation of the furnace with this feed was that the dust losses were higher. This shows that only a small amount of draft could be used with very fine feed. The calcine from this test had a sulphur content of 2.0% which was 0.3% less than that of the calcine obtained by roasting the regular concentrates.

The increase in sulphur removal shows that grind does have an effect on the completeness of the oxidation reaction. The decrease in the sulphur content was quite small, and it is very doubtful if it would be economical in practice to grind to such a fine size.

The increase in dust losses is a disadvantage in using very fine feed. The practice of mixing very finely ground concentrates with hot oxygen might lead to an explosion. This test indicated that regular flotation concentrates would probably prove to be the most economical and satisfactory feed.

The next test for this investigation was run by using the same furnace temperature as before but with an air atmosphere instead of oxygen. The feed for this test was the same as that used in the first test. The reason for using this test was to obtain calcine to compare with that from a test using oxygen as the atmosphere.

The calcine from the air roast contained 15% sulphur and showed no signs of fusion. The higher sulphur content revealed that the material had not fallen far enough through an oxidizing atmosphere to give the same amount of sulphur removal as did the other test. A much higher shaft could be used to get better sulphur elimination, but the oxidation would take place over a greater period of time and the fusion temperature would probably not be reached. The excess gases and high furnace would cause much greater heat losses.

No test was tried with varying amounts of draft. The amount of draft would have an effect on both the chemical and physical properties of the calcine and the amount of circulating dust. A large amount of draft would cause the particles to fall more slowly if counter current draft were used and thereby remove more sulphur, but, at the same time, it would cause a high circulating dust load.

The tests clearly showed the results of varying the oxygen content in the roasting atmosphere, and using very fine feed. They showed that the oxygen content of the roasting atmosphere had a much greater effect on the operation than did excessive grinding of the feed. In a plant operation, it would be much easier and cheaper to control the oxygen content of the roasting atmosphere and the amount of draft than it would be to fine grind the feed in order to obtain a desired product. The feed could not be excessively coarse, but the average flotation concentrate would be sufficiently fine.

The tests did not reveal any difficulties that would be caused by overheating of the furnace. It was found that the furnace temperature could be controlled within certain limits by the rate of feeding.

During the tests, accretions built up on the thermocouple wells and around the discharge end of the shaft. Calcine collected on the edge of the hearth and fused to start accretions which grew and formed on the bottom of the shaft. This problem was not serious and could probably be eliminated by having the shaft over the center of the hearth rather than over the back edge. The shaft in the center of the hearth would permit all of the calcine to fall free and collect in the bottom of the hearth.

Variations in the rate of feeding caused the combustion zone to move up and down the shaft, but in this small furnace there were no explosive results. However, in a larger furnace it would pay to investigate this matter further.

Larger equipment operated over a longer period of time would undoubtedly develop other difficulties, but they would probably not be unsurmountable. In such an operation it would be possible to control operating conditions more closely and obtain a desired product.

CONCLUSIONS

The experimental results which have been presented indicate the following conclusions:

1. Large amounts of heat are retained by sulphide particles which are roasted in an oxygen atmosphere. The sinter which was formed by the calcine indicated that the material was very hot when it entered the hearth. The hearth temperature was not great enough to form a sinter if cold concentrates were dropped into it.

2. A near dead roast can be obtained by roasting in oxygen. The tests showed that this was possible without using excessively fine feed or a high shaft.

3. Temperature, fineness of feed, oxygen content of the roasting atmosphere and rate of feeding affect the chemical and physical properties of the calcine.

4. Accretions would not be a serious problem.

5. Refractory trouble caused by overheating would not be great. It was found that it was possible to control the furnace temperature within reasonable limits.

6. Good insulation for the shaft is required. Lower heat losses make a higher rate of feeding possible.

7. Flotation concentrates are sufficiently fine to give good results.

RECOMMENDATIONS

The following suggestions for future experimentation are presented:

1. Tests could be made using concurrent draft. Such tests would help determine which type of draft would be better.

2. A furnace which would be large enough to permit good control of operating conditions could be tried.

3. A furnace could be designed with a shaft over the center of the hearth to try to eleminate accretions.

4. A mechanical feeder which would give a constant rate of feeding could be tried.

5. Effort could be made to estimate the capacity of this type of roaster.

6. Work could be done in igniting the concentrates as soon as they entered a shaft roaster using counter current draft.

7. A furnace using counter current draft with a dust settling chamber directly over the shaft could be tried.

8. Tests could be made to determine the result of varying the amount of draft.

9. Tests could be made using moist feed.

10. Tests could be made over an extended period of time to see if the heat from the oxidation would be great enough to carry on the operation.

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